R70-114

Reprinted from FOOD TECHNOLOGY, Vol. 24, No. 8, Pages: 60–64

Development of INTERMEDIATE MOISTURE FOODS *for Military Use*

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☐ THE TERM "intermediate moisture," has entered our vocabulary during the past decade to identify a heterogeneous group of foods which resemble dry foods in their resistance to microbial deterioration but which contain too much moisture to be regarded as dry. Several members of this group such as air dried figs and dates were used by man before the dawn of recorded history.

In addition to the common dried fruits, the intermediate moisture group includes soft candies, marshmallows, jams and jellies, a number of baked items such as fruit cake, peperoni and other types of dry sausage, pemmican, jerky, and country ham. Although these products normally contain 20 to 30 percent water they resist microbiological spoilage without refrigeration.

Characteristics of IM Foods

INTERMEDIATE MOISTURE FOODS are plastic, easily masticated and do not produce an oral sensation of dryness. Notwithstanding their microbiological stability, intermediate moisture foods are subject to the same types of adverse chemical changes as observed with fully dehydrated foods. As a generalization, foods in the intermediate moisture range are more susceptible to the Maillard reaction than "dry" foods but less susceptible to fat oxidation (Loncin et al., 1968). Unless precautions are taken to inactivate enzymes, intermediate moisture items are susceptible to a variety of enzymic reactions (Acker, 1969).

The empirical requirements underlying the preparation of intermediate moisture foods have been known for many years; however, commercial development of new items has been mainly confined to pet foods (Burgess and Mellentin, 1965; 1969). This effort has no doubt been facilitated by the availability of acceptable antimycotics which are effective for suppressing the growth of yeast and mold.

WATER ACTIVITY

THE BINDING, immobilization and other types of restraint imposed on the behavior of the water present in food is mediated by a multiplicity of systemic factors such as the nature and concentration of dissolved components, the number and binding capacity of polar residues including those with negative coefficients, see Bull (1968), the configuration of hydrophobic and hydrophilic areas, and, presumably, the mechanisms which alter the structure of water itself.

The availability of water for spore germination and microbial growth is closely related to its relative vapor pressure, commonly designated as water activity. Water activity (a_w) is defined as the ratio of the vapor pressure (P) of water in the food to the vapor pressure of pure water (P_o) at the same temperature, $a_w = P/P_o$. Within the range favorable to the growth of mesophilic microorganisms, a_w is practically independent of temperature.

MOISTURE SORPTION ISOTHERMS

WHEN EQUILIBRIUM EXISTS between the water content of a food and the percent relative humidity of its environment (RH), a_w is directly relatable to RH, $a_w = RH/100$. The relationship between a_w (or RH at equilibrium) and the moisture content of a food is precisely described by its moisture sorption isotherm—such as shown in Figure 1 for egg albumin.

The physical-chemical phenomena underlying sorption isotherms have been the subject of extensive analyses and theoretical speculation, see Labuza (1968), particularly in the zone below a_w 0.3 or 0.4 which includes most dehydrated foods. Without reference to theories which provide an insight into the mechanisms which lower the vapor pressure of water in food, it is apparent from the moisture sorption isotherm for egg albumin (Fig. 1) that as the moisture concentration decreases, a progressive restraint is exercised on the vapor pressure of the residual water as evidenced by the a_w values. Thus, according to Figure 1, the 3.5 to 4.0 g of water which remain in 100 g of dry egg albumin have a vapor pressure equal to only one-tenth that of pure water.

WATER ACTIVITY & MICROBIAL GROWTH

AS A CONVENIENT working generalization, the a_w scale can be regarded as an index or an "availability" scale for water in the vital processes incident to microbial growth.

The literature summarized by Scott (1957, 1961), Mossel and Ingram (1955), Christian (1963), Frazier (1967), and others, indicates that spores can not germinate and relatively few species of bacteria, including only one food pathogen, can multiply at $a_w = 0.90$. Under favorable conditions *S. aureus* has been observed to grow at a_w as low as 0.86. Halophilic bacteria may grow at a_w as low as 0.75, which corresponds to a saturated solution of sodium chloride. The common species of yeast and mold are suppressed at a_w 0.88 and 0.80, respectively, while the limits for xerophilic molds and osmophilic yeast are stated to be 0.65 and 0.60, respectively.

Based solely on the potential limits of microbial growth, an intermediate moisture food would be required to have $a_w = 0.60$ or less. At this a_w most common foods would be difficult to distinguish from their "commercially" dry counterparts. For prolonged storage of food the recommendations cited by Scott (1957) run between a_w 0.65 and 0.75. These recommendations are largely concerned with grains which are highly susceptible to mold deterioration. Moreover the a_w of cereal grains has an exaggerated response to small increases in moisture. An increase of 2% moisture, for example, can increase a_w from a safe 0.70 to a level at which spoilage starts within a few days. In recommending limits of a_w for foods, consideration must be given to the nature of the food, its history, processing, packaging and the conditions of its storage and handling.

Food which has been subjected to heat processing sufficient to destroy vegetative microorganisms and which is protected from subsequent contamination by reliable packaging, presents an acceptable risk at a_w as high as 0.90. Substantial support for such products can be drawn from the experience of the Armed Forces with pasteurized bacon, prefried bacon, and several varieties of canned bread. Additional evidence for the microbiological safety of the latter group of products has been developed in the laboratories of the National Canners Association. Such products also qualify as intermediate moisture foods.

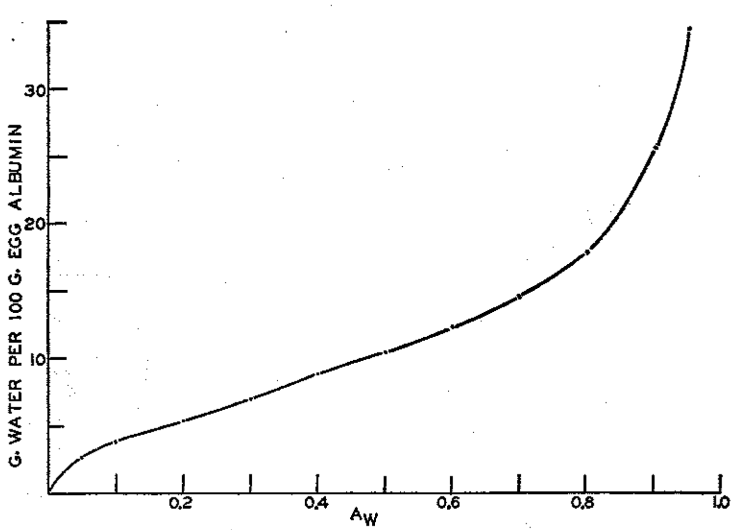

Fig. 1—Moisture sorption isotherm for freeze-dried egg albumin (data from Bull 1944).

By incorporating an effective antimycotic agent, heating to destroy vegetative organisms, and adjusting to a_w of approximately 0.85, pet foods sealed in inexpensive plastic pouches have an excellent record for stability under market conditions.

POTENTIAL ADVANTAGES OF IM FOODS

INTERMEDIATE MOISTURE FOODS offer several potential advantages for special military situations. In the first place these foods are relatively low in moisture and hence can be considered concentrated from the standpoint of weight, bulk, and caloric content. Since they are plastic, they can be molded into cohesive blocks of uniform geometry to facilitate packaging and storage. These advantages favor use under circumstances in which resupply is unreliable and the soldier must add to his already immoderate load whatever food he will consume on missions lasting for as long as 8 days.

Intermediate moisture foods are suitable for direct consumption with no preparative effort, save removal of a protective wrapper. Such foods can be used in stress situations in which diversion of time or attention to the preparation of food is hazardous.

In contrast to freeze dried products, intermediate moisture foods are more acceptable for direct consumption in that they do not give rise to the sensation of harsh dryness. Moreover their texture is much closer to normal food than the crisp or rigid structures of fully dehydrated foods.

In contrast to the heat sterilized canned products which currently provide the main components of our combat type rations, the wholesomeness or safety of intermediate moisture foods is less dependent upon the integrity of their containers. This built-in safety feature is of real significance in designing food to be delivered by air-drop.

CURRENT IM FOODS NOT SUITABLE

NOTWITHSTANDING the advantages mentioned above, the inventory of currently available intermediate moisture foods is largely unsuitable for military feeding. Foods such as dried fruits, confectionery and bakery products, while acceptable per se, have limited application. While peperoni and dry salami have an exceedingly high caloric value per unit weight, these and other intermediate moisture meats are too high in salt to qualify as major ration components.

The availability of a wide variety of intermediate moisture foods of demonstrated acceptability is regarded as essential prerequisite to an expanded use of such foods for military feeding.

PROBLEMS in Developing NEW IM Foods

A MAJOR OBSTACLE in converting familiar foods into intermediate moisture items is apparent from the moisture sorption data shown in Table 1. Many common foods are too dry to be acceptable for direct consumption even at a_w 0.85. Potential relief from this situation is seen in the case of apples which contain 61 g of water per 100 of dry material (37% by weight). Apples and currants contain a substantial concentration of sugar.

Likewise, the intermediate moisture foods cited in the first paragraph contain large amounts of either sugar or salt in proportion to the amount of water present.

Table 2 extends the data of Table 1 to include a_w values for aqueous solutions containing 100 g of anhydrous sodium chloride, glycerol, and sucrose. Sodium chloride and to a lesser extent glycerol have the capacity to depress

Table 1—Moisture sorption data for common foods and food components.

Product	Temp. (°C)	Water g/100 g dry material [a] for a_w = 0.70	0.75	0.80	0.85	0.90	Reference
Rice	30	13.2	14.5	16.2	18.4		Melpar (1965)
Milk non-fat	30	11.9	13.5	15.8	19.8		Melpar (1965)
Egg Albumin [b]	25	14.5	15.8	17.8	21.0	25.5	Bull (1944)
Wheat	25	16.3	17.5	19.3	22.0	25.8	Ayerst (1965)
Chicken [b,c]	20	18.2	20.3	22.7	25.9		Hanson (1961)
Beef [b,c]	25	16.7	19.8	23.4	27.5	34.6	Wolf (1970)
Peas [b]	20	16.4	19.6	23.0	29.0		Hanson (1961)
Shrimp [b]	35	16.9	19.2	23.2	29.4		Melpar (1965)
Gelatin	25	21.6	23.5	26.7	31.6	40.2	Bull (1944)
Currants [b]	20	25.2	31.5	39.4	51.0		Hanson (1961)
Apple [b]	30	30.2	35.8	43.7	60.6		Melpar (1965)

[a] Some values calculated or interpolated from cited data
[b] Freeze dried
[c] Fat-free basis

the vapor pressure of proportionally large amounts of water.

Compared to the values for food in Table 1, sucrose is substantially more effective gram for gram than protein or starch. Relevant to product safety is the strong stabilizing effect of the compounds of Table 2 on a_w. Thus 22 g of water are needed to raise a solution containing 100 g of sucrose from a_w 0.85 to 0.90. Solutions of glycerol and salt require far greater amounts of water. On the other hand, from Table 1 only 3.8 g of additional water would raise the a_w value of a corresponding weight of wheat from 0.85 to 0.90.

ADDITIVE PROBLEMS

ALL ADDITIVES CITED have undesirable characteristics in the concentrations required to control a_w. Sucrose imparts a distinctly sweet taste which would be abnormal to many products.

The most attractive possibility with the additives at hand is a combination of salt and glycerol. Glycerol has less flavor impact than either glucose or sucrose and, for practical purposes is non-volatile, is well tolerated physiologically and is metabolized to yield 4.3 kcal per g. Salt would be used only to a normal level of seasoning.

Continuing effort is needed to find additional additives acceptable for food use which can replace part of the glycerol currently required to depress a_w.

For non-ionic compounds, limited guidance is provided by Raoult's law which approximates the relationship between the moles of water and the moles of solute in a solution and its a_w. In addition to the additives for depressing water activity, a low concentration of an antimycotic is introduced to suppress growth of mold and yeast.

WATER ACTIVITY PROBLEMS

WHATEVER THE ADDITIVES, it is essential that the aqueous phase present in the food be brought uniformly to the desired level of water activity. In commercial production of intermediate moisture foods, this is generally achieved by concentrating the solute through evaporation of water. In the case of dry sausage, salt is introduced into the meat and subsequently concentrated by evaporation.

Aside from the problems of introducing glycerol and salt and antimycotic into a food mass, experience has shown that evaporation of water from products with a high solute content must be carefully controlled to avoid "case hardening" and accumulation of solute at the surface.

Equilibration Procedure May Solve Problems

EXPERIMENTAL EVIDENCE points to the technical feasibility of preserving a great variety of foods in the intermediate moisture range by equilibrating (and cooking) in an aqueous solution of glycerol, salt and antimycotic.

Food is immersed in a solution of such predetermined composition that after equilibration with the aqueous phase of the food, the food would have the desired a_w and concentration of antimycotic. Comparison of $NaCl/H_2O$ ratios following equilibration for the external and internal aqueous phases has established that slices 1 cm thick completely equilibrate following cooking at 95–100°C in a water bath and holding overnight in a refrigerator.

With items which had been previously cooked, such as canned items, and with vegetables which responded un-

Table 2—Moisture sorption data for pure chemical compounds.

Compound at 25°C	Water g/100 g anhydrous compound for a_w = 0.70	0.75	0.80	0.85	0.90	Reference
Sodium Chloride	[a]	277	332	423	605	Olynyk & Gordon (1943)
Glycerol	56	72	96	132	203	Nat. Bur. Std. (1951)
Sucrose	[a]	[a]	[a]	49	71	Scott (1957)

[a] Beyond solubility limit.

Table 3—Preparation of representative intermediate moisture foods by equilibration.

Initial material	% H_2O	Ratio:[a] Initial Wt. / Solution Wt.	Processing	Equilibrated product H_2O %	Equilibrated product a_w
Tuna, canned water pack pieces 1 cm thick	60.0	0.59	cold soak	38.8	0.81
Carrots diced 0.9 cm cooked	88.2	0.48	cook 95–98°C refrig	51.5	0.81
Macaroni, elbow cook, drain	63.0	0.43	cook 95–98°C refrig	46.1	0.83
Pork loin, raw 1 cm thick	70.0	0.73	cook 95–98° refrig	42.5	0.81
Pineapple canned, chunks	73.0	0.46	cold soak	43.0	0.85
Celery 0.6 cm cross cut blanch	94.7	0.52	cold soak	39.6	0.83
Beef, ribeye 1 cm thick	70.8	2.35	cook 95–98°C refrig		0.86

[a] For composition of equilibration see Table 3A

favorably to cooking, equilibration was achieved through prolonged soaking under refrigeration.

MANY FOODS PREPARED BY EQUILIBRATION

EQUILIBRATION PROCEDURES have been applied to beef, pork, chicken, lamb, ham, tuna and to a variety of non-meat items such as peas, carrots, mushrooms, onions, potatoes, pineapple, celery, macaroni and egg noodles. Representative examples of the preparation of various intermediate moisture foods by the equilibration technique are shown in Table 3.

Consideration has also been given to the development of various sauces and gravies which in combination with intermediate moisture foods yield a variety of casserole type items such as beef stew, creamed tuna and noodles, chicken a la king, Hungarian goulash, and sweet and sour pork. Table 4 represents a formulation for an intermediate moisture sauce for this latter product. With the exception of the last item of Table 3 (Beef, ribeye, 1 cm thick), all experimental products cited were developed at the Technical Center of General Foods Corporation (1968, 1970).

SENSORY PROPERTIES

EXCEPT FOR a slight but recognizable sweet taste, foods adjusted to an a_w of 0.80 to 0.85 have normal sensory properties. In general, meat items with a_w above 0.80 are soft, moist, and tender but retain a fibrous structure normal to meat texture.

Odor of all meats is uniformly normal. Taste is somewhat sweeter than normal but recognizable as cooked pork, beef, chicken, lamb and tuna.

Flavor of beef and pork improve with addition of soup and gravy base to the immersion solution. It is believed

Table 3A—Composition of equilibration solutions.

Components of solution %	Products equilibrated: Tuna	Carrot	Macaroni	Pork	Pineapple	Celery	Beef
Glycerol	53.6	59.2	42.7	45.6	55.0	68.4	87.9
Water	38.6	34.7	48.8	43.2	21.5	25.2	—
Sodium chloride	7.1	5.5	8.0	10.5	—	5.9	10.1
Sucrose	—	—	—	—	23.0	—	—
K Sorbate	0.7	0.6	0.5	0.7	0.5	0.5	—
Na Benzoate	—	—	—	—	—	—	2.0

Table 4—Composition of intermediate moisture sauce for sweet and sour pork.

Glycerol	25.00%
Catsup	23.84
Water	15.00
Vinegar	13.50
Sucrose	11.84
Starch Hydrolyzate, 15 DE	4.22
Sodium Chloride	2.59
Corn Starch	2.30
Monosodium Glutamate	1.15
Potassium Sorbate	0.30
Mustard Powder	0.23
Onion Powder	0.02
Garlic Powder	0.01

Sauce: Moisture 34.9%
a_w 0.85

that intermediate moisture meats would be accepted in casseroles and combination dishes in which a slight sweetish taste is a normal attribute.

Fruits and vegetables generally retain a near-normal color, texture and appearance. After storage for 3 months celery even retains a marked crispness. Flavor retention is variable. Carrots exhibit excellent flavor retention while peas lose much of their identity.

STORAGE STABILITY

NO MICROBIOLOGICAL development or significant chemical, physical or sensory changes have been noted during 4 months storage in sealed containers at 38°C.

Some difficulty has been encountered with a phase separation of certain sauces under the above storage conditions. Standard plate counts have been performed at the time of preparation and after 4 months storage. There is a well defined trend toward a reduction in viable bacteria during storage. Counts for yeasts and molds are reported as less than 10 per g.

Two intermediate moisture casserole items, chicken a la king at $a_w = 0.85$ and ham in cream sauce at the same a_w were inoculated with *S. aureus* (12,000–14,000 organisms per g). After 1 month at 38°C the viable count had fallen to less than 2,000 and after 4 months it was listed for both products as 0.4 organisms per g. Comparable observations were made on the same two items after inoculation with *E. coli*, Salmonella, and vegetative cells of *Cl. perfringens*.

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Adapted from a paper presented at the 29th IFT Annual Meeting in Chicago.

This paper reports research undertaken at the U.S. Army Natick (Mass.) Laboratories and has been assigned No. TP. 593 in the series of papers approved for publication. The findings in this report are not to be construed as an official Department of the Army position.